- *Nucleation*
  - *homogeneous*
  - *heterogeneous*
- *Growth*
  - *planar*
  - *dendritic*
- *Casting*
  - *microstructure*
  - *defects*
- *Welding*

Taking a close look at solidification…

- Solidification $\Rightarrow$ freezing of metal
- Nucleation occurs when a small piece of solid forms from the liquid.
- $\Delta T = T_m - T$ is the amount of undercooling.

Why does a liquid become a solid?

(below the melting point the free energy of the solid is less than the liquid)

What factors affect nucleation?

(anything that makes r* smaller makes nucleation easier – see next slide)

Nucleation

$$\boxed{r^* = \frac{2\sigma T_m}{\Delta H_f \, \Delta T}}$$

where σ is the surface energy, T_m is the melting point in K, ΔT is undercooling in ^oC or K, and ΔH_f is the latent heat of fusion.

Which variable can we most easily control?

(undercooling. Faster cooling rate, more undercooling)

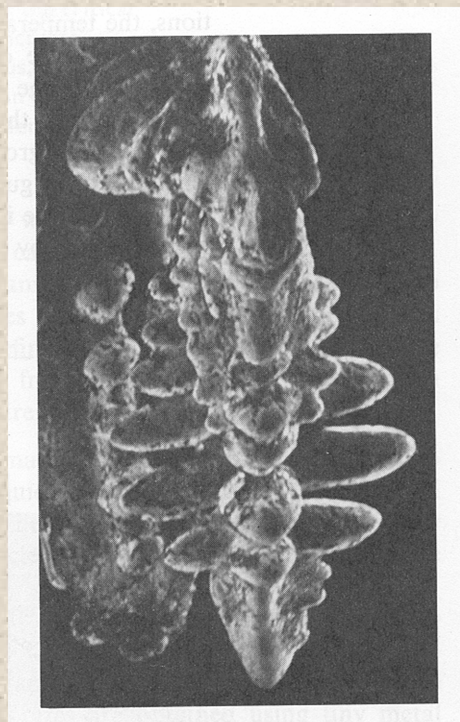
Heterogeneous Nucleation

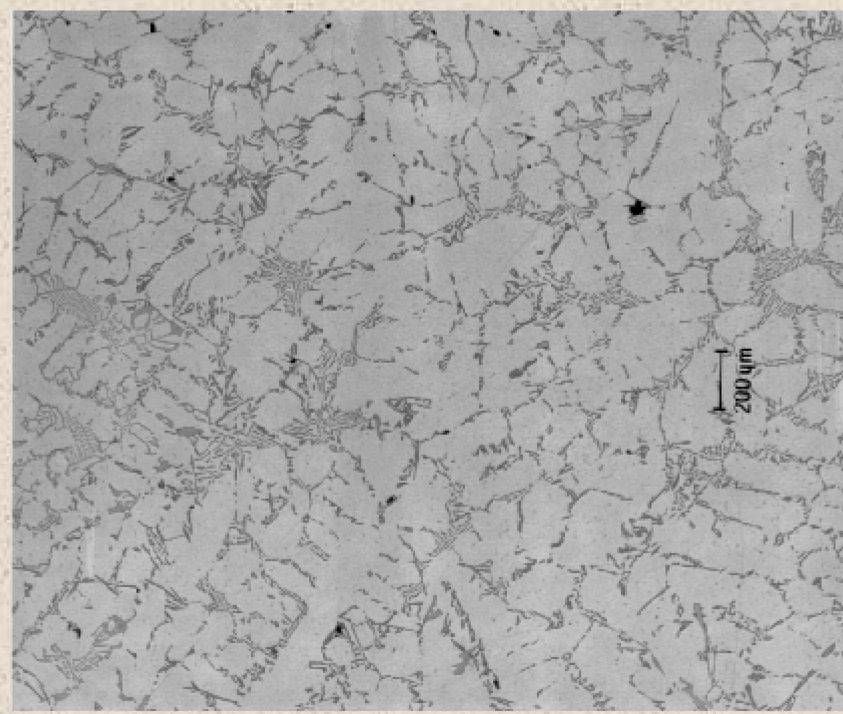
- Homogenous nucleation never occurs except in laboratory experiments because ΔT required for heterogeneous nucleation usually smaller.
- <u>Heterogeneous nucleation</u>
  - impurities provide a surface for solid to nucleate
  - intentional additions called <u>inoculants</u> encourage this and are used for <u>grain refinement</u>
- <u>Glasses</u> form when cooling rates are too high for nucleation to occur.

Growth

- Growth of the solid occurs as atoms from the liquid are attached to the solid.
- For growth to occur, the latent heat of fusion (ΔH_f) must be removed from the liquid.
  - Planar growth
  - Dendritic growth
- More inoculation, less undercooling required $\Rightarrow$ more planar growth
- Otherwise you see dendritic growth

Dendritic microstructures





- Faster cooling ⇒ smaller <u>secondary dendrite arm spacing</u> (SDAS)
- Smaller SDAS ⇒ higher strength and improved ductility

Casting

- Molten metals are poured into molds and allowed to solidify
- Superheat is difference between T_m and pouring temperature
- Ingot: as-solidified shape that will undergo additional processing
- Casting: as-solidified component (an ingot is a casting)

Show sand casting process

Casting

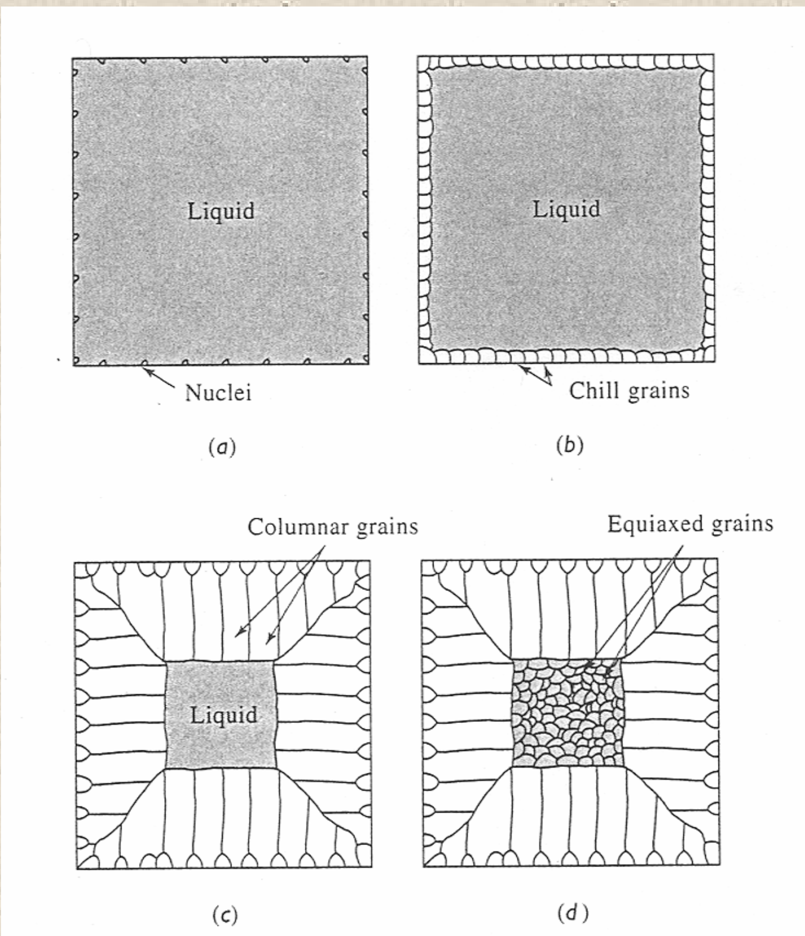
- The total solidification time (t_s) for a casting can be described by Chvorinov's rule:

$$t_s = B\left(\frac{V}{A}\right)^n$$

- where V= casting volume, A is casting surface area and n $\approx$ 2.
- B is the mold constant and depends on the pouring temperature and the mold properties.

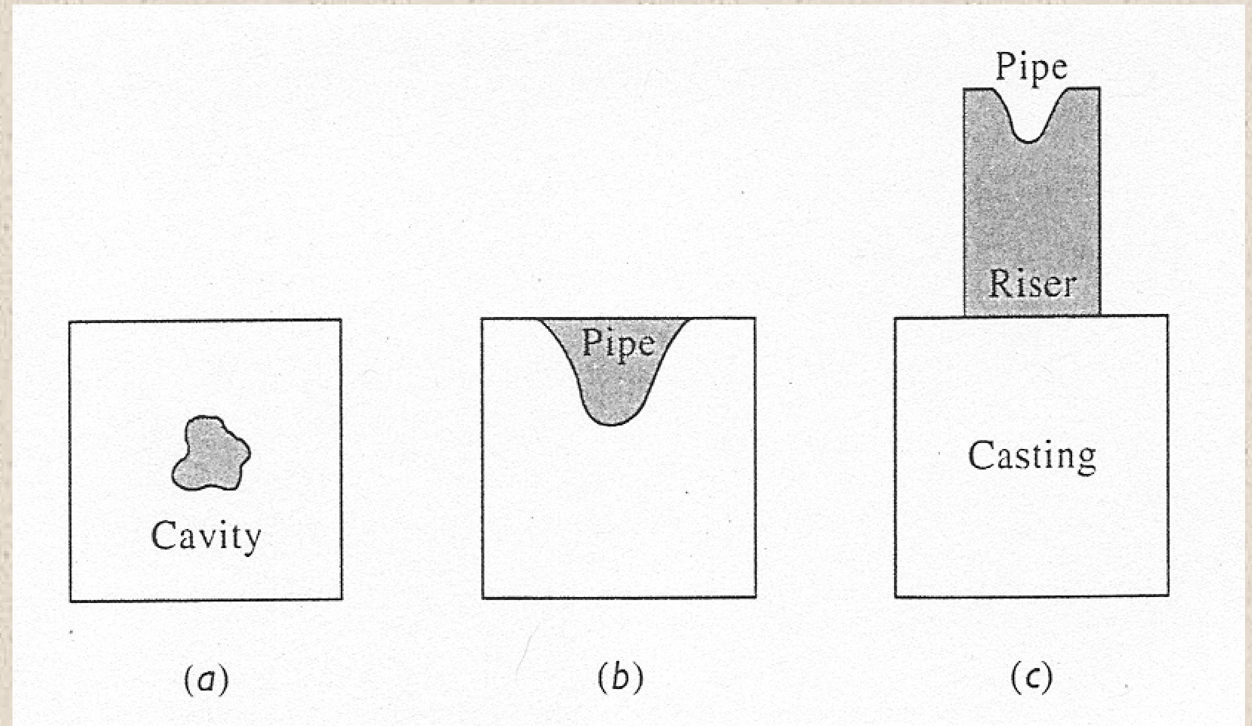
Casting macrostructure

- As-solidified <u>macrostructure</u>
  - <u>Chill zone</u> heterogeneous nucleation of tiny grains at mold wall
  - <u>Columnar zone</u> elongated grains that grow perpendicular to mold wall
  - <u>Equiaxed zone</u> randomly oriented grains in casting center, last to cool and solidify.



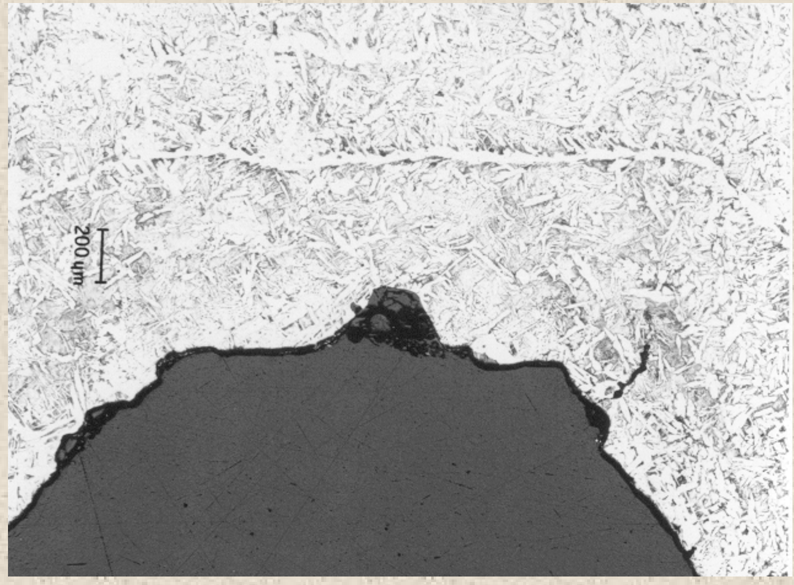
Solidification Defects

- <u>Shrinkage</u>: as material solidifies, it will contract



Solidification Defects

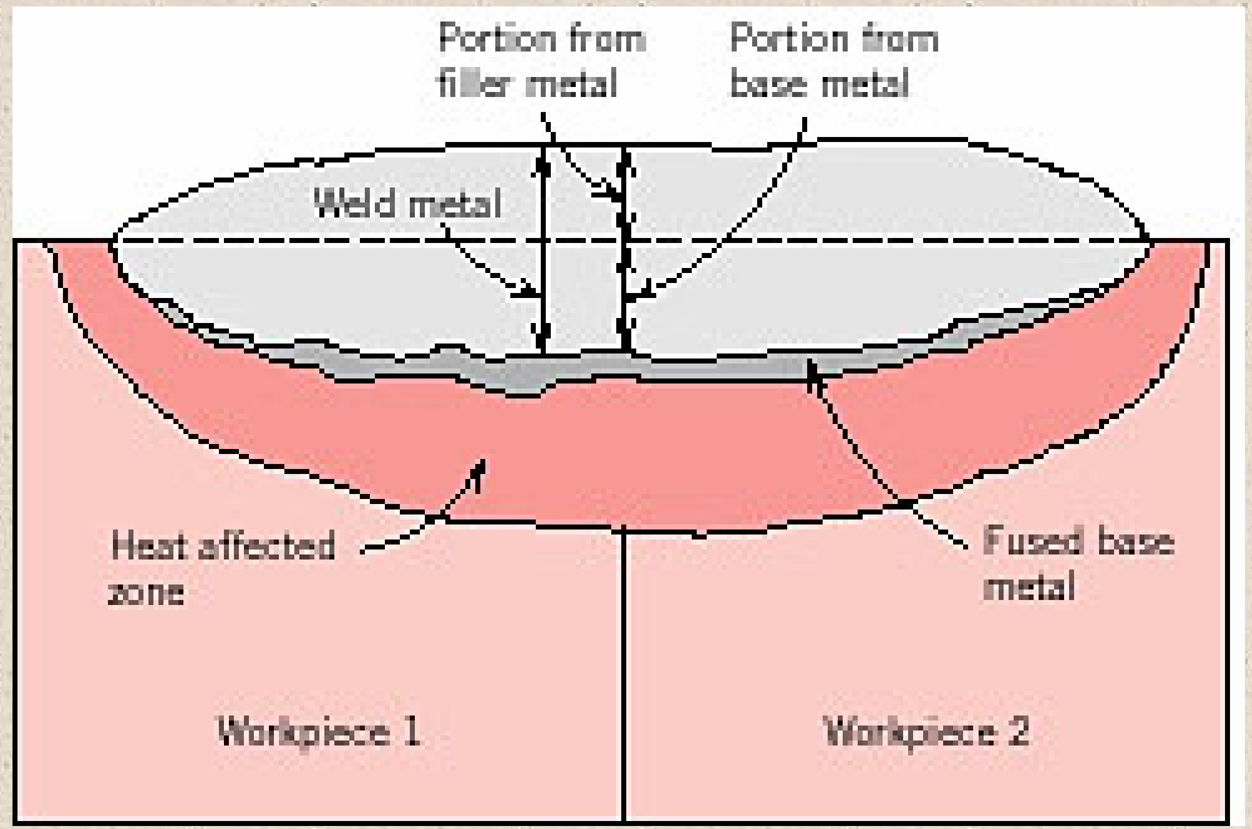
- Shrinkage porosity – shrinkage between dendrites
- Gas porosity – solubility of gas in liquids are typically higher than solids. Gas is rejected as it solidifies and can get trapped as bubbles.



Welding

- Metals to be joined are melted and fused together with a filler metal.
- The melted and re-solidified material is, in a sense, a casting, and is called the fusion zone.
- Microstructure surrounding the fusion zone changed as a result of the weld is called the heat-affected zone (HAZ).
- Variables that affect the HAZ microstructure: metal thickness and T_m, heat input, cooling rate.

Weld structures



Weld structures